# Geosynchronous Imaging of the Earth's Ionosphere: Development Phase

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## LONG-TERM GOALS

Under ONR grant N00014-01-1-0702 we explored the value of airglow imagers in the study of the ionosphere. In large part this effort was driven by the need to develop new ways to characterize the Earth's ionosphere, a major thrust at the Naval Research Laboratory in the past decade and one that still continues. These instruments include optical sensors which are already being tested in low earth orbit and future plans include placing ionospheric airglow imagers on satellites in geostationary orbit.

## OBJECTIVES

The objectives of the project were:

(1) to continue to develop the rationale for space-based optical instruments;

(2) to show the usefulness of current (ground-based) imaging systems for space research;

(3) to begin using data assimilation as a tool for Space Weather research.

## APPROACH

We organized research programs at two locations: Arecibo, Puerto Rico and Maui, Hawaii. The former was centered about the National Astronomy and Ionosphere Center and the latter at the Air Force's Advanced Electro-Optics System.

Our role in the Arecibo Campaign was to propose for the radar time, participate in radar data analysis, field our all-sky imager, analyze the resulting data, and organize publication of the results. The primary goal here was to use data assimilation methods.

In the Maui effort we first fielded the dual camera system and published its initial results in *Geophysical Research Letters*. We then followed this work with a long data accumulation period, which we plan to publish soon. (We also made the first ground truth comparison with the on-orbit imager, GUVI, on the TIMED satellite, a comparison that appeared on the cover of *Geophysical Research Letters*.)

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14. ABSTRACT

**Under ONR grant N00014-01-1-0702 we explored the value of airglow imagers in the study of the ionosphere. In large part this effort was driven by the need to develop new ways to characterize the Earth???s ionosphere, a major thrust at the Naval Research Laboratory in the past decade and one that still continues. These instruments include optical sensors which are already being tested in low earth orbit and future plans include placing ionospheric airglow imagers on satellites in geostationary orbit.**

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**WORK COMPLETED**

The Data Assimilation project was centered on data taken during Space Weather Month in September, 1999. One of our contributions to the data set is reproduced in Figure 1 and shows ionospheric variability over seven almost consecutive nights at mid-latitudes. The eighth panel shows what the climatological model, IRI, predicts for this same period. Major differences occurred from night to night with little relationship to the IRI.

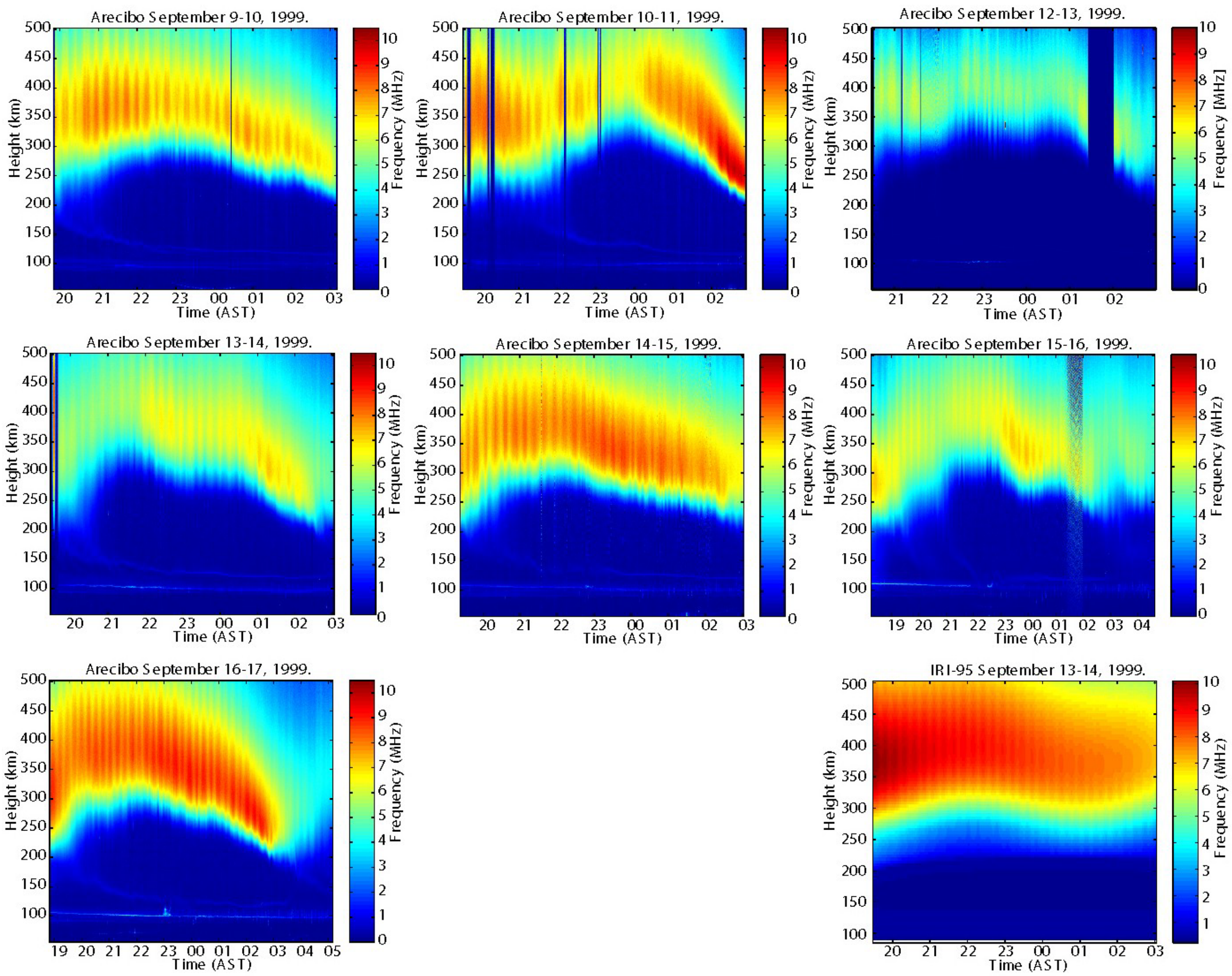


***Figure 1. Summary of the nighttime observations during CIC99 plotted in units of plasma frequency. Panel 8 is a result of running the IRI-95 model, using the elevation and azimuth information for September 13-14, 1999. The bands are caused by gradients in electron density detected as the antenna feed was rotated at a constant zenith angle of 15°.***

The results were summarized in four papers accepted for publication in the *Journal of Atmospheric and Solar-Terrestrial Physics*:

Kelley, M.C., A. Sur, J.J. Makela, and M.N. Vlasov, Further studies of the Perkins stability during space weather month, *J. Atmos. Solar-Terr. Phys*., in press, 2003.

Makela, J.J., M.C. Kelley, S.A. González, N. Aponte, and J.J. Sojka, Midlatitude plasma and electric field measurements during Space Weather Month, September 1999, *J. Atmos. Solar-Terr. Phys*., in press, 2003.

Sojka, J., D.C. Tompson, R.W. Schunk, J.V. Eccles, J. J. Makela, M.C. Kelley, S.A. Gonzalez, N. Aponte, and T.W. Bullettl, Ionospheric data assimilation: Recovery of strong mid-latitudinal density gradients, *J. Atmos. Solar-Terr. Phys*., in press, 2003.

Vlasov, M.N., M.C. Kelley, J.J. Makela, and M.J. Nicolls, Intense nighttime flux from the plasmasphere during a modest magnetic storm, *J. Atmos. Solar-Terr. Phys*., in press, 2003.

**RESULTS**

The results are summarized as follows:

(1) Data assimilation models can yield what seem to be valid results by incorrectly adjusting free parameters. This problem was discovered when an analytical model allowing plasmaspheric fluxes was found to better explain the ionospheric behavior on September 16-17, 1999 [*Vlasov et al*., 2003] than the data assimilation model, AIM 1.06. These fluxes were included in AIM 1.07 with much improved results [*Sojka et al*., 2003].

(2) A very active equatorial fountain effect was found to occur on this night and led to the intense plasmaspheric fluxes. This was consistent with the electric field patterns for this night [*Makela et al*., 2003].

(3) A simple analytical model for ionospheric dynamics based on the work of *Perkins* [1973] was developed [*Kelley et al*., 2003], which also verified the need for a plasmspheric source over Arecibo on Sept. 16-17.

In the Hawaii sector we showed the power of a dual camera system for Equatorial Spread F studies. Figure 2 shows the merging of the two images and reveals an equatorial bubble from its initial source at the base of the equatorial ionosphere to its apex height on magnetic field lines, which map to overhead in Hawaii. The four panels show the evolution of several bubbles over two hours.

In addition, we made GPS scintillation observations, as shown in Figure 3. Whenever the line of sight to GPS passes through a depleted light zone, scintillation rose dramatically. TEC data were lost during the most severe events. This shows the potential for navigational problems during such severe disturbances, even over a mid-latitude site such as Hawaii.

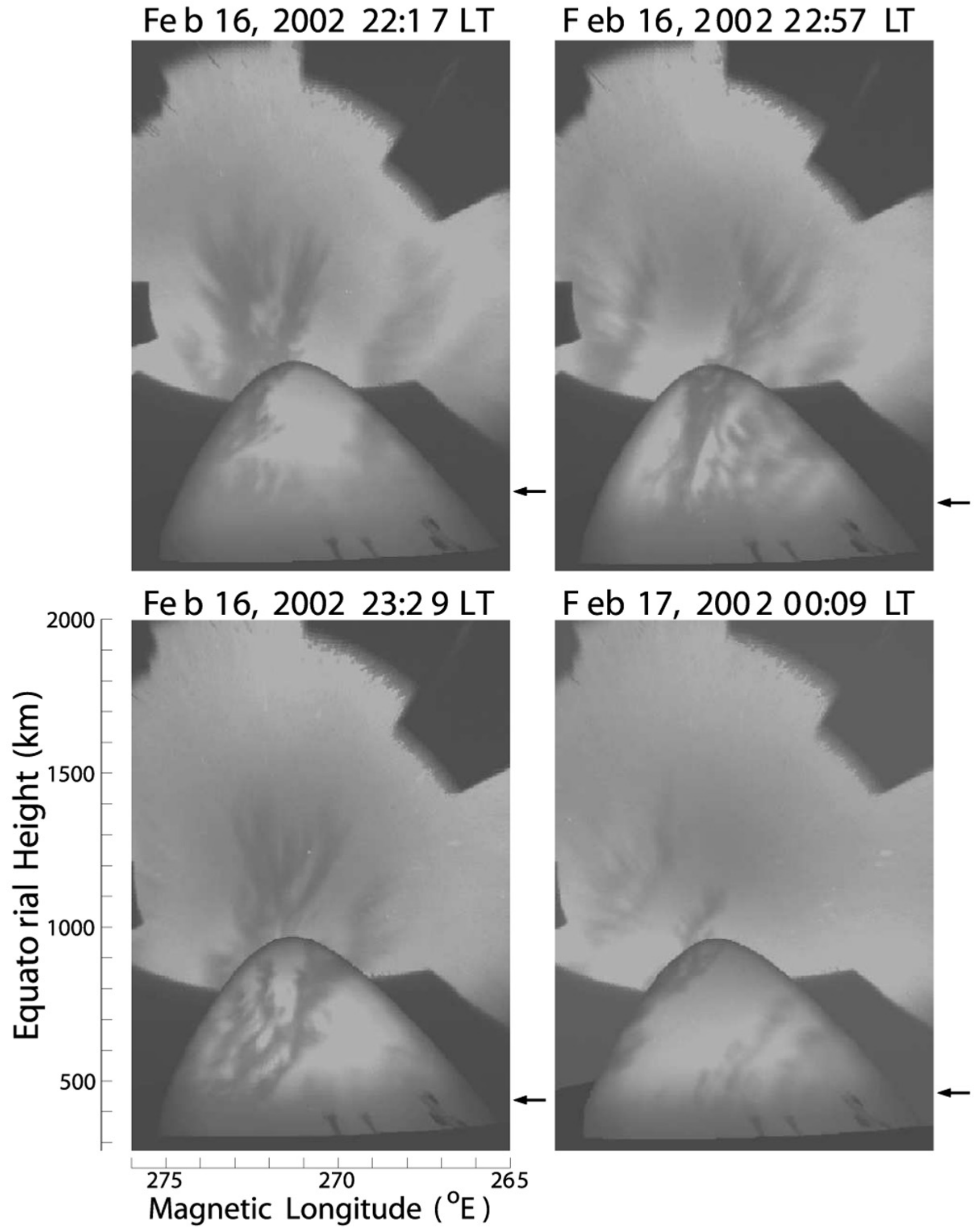


***Figure 2. Composite of near-simultaneous images taken with CNFI (bottom portion of each image) and CASI (top portion of each image) for four different times on February 16-17, 2002. The images have been projected along the magnetic field lines to the magnetic equator. The images were taken using the 557.7 nm filter.***

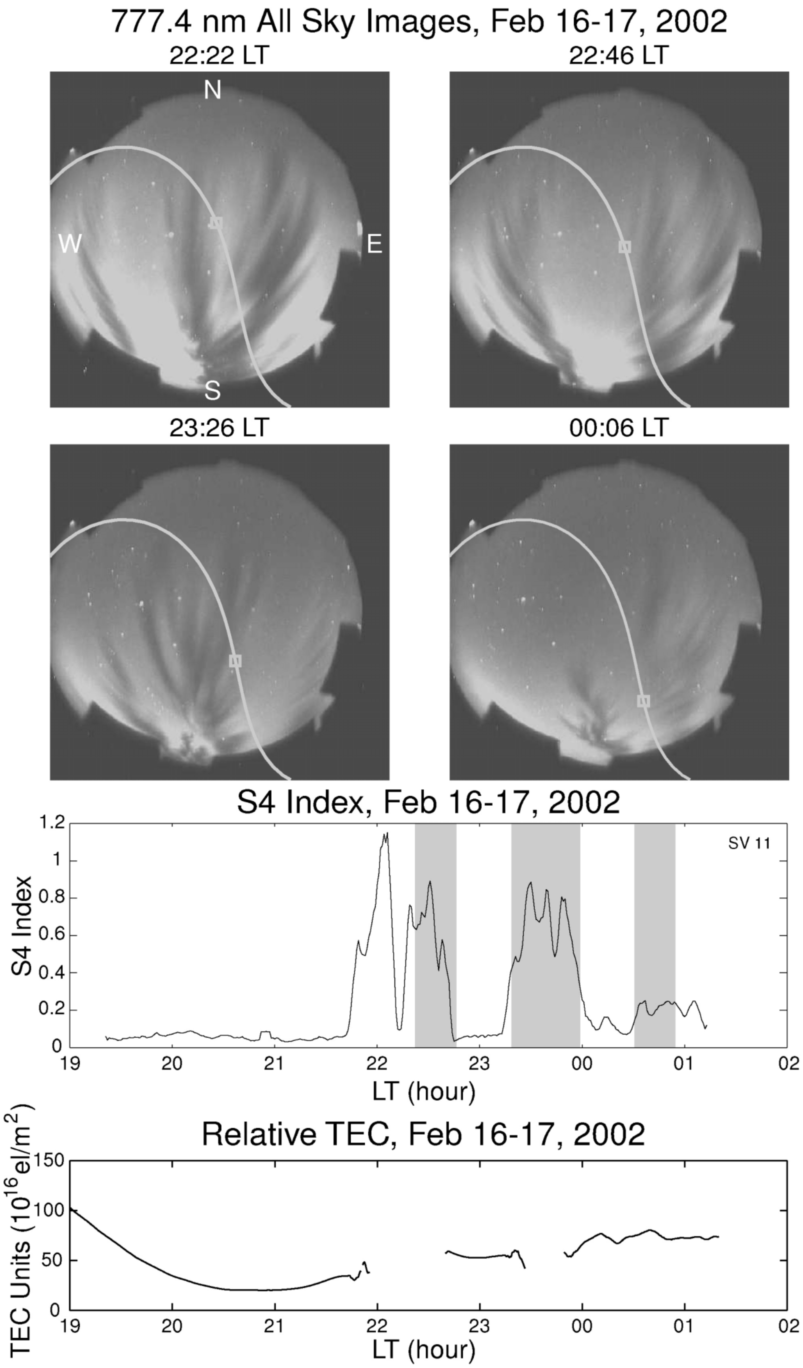


***Figure 3. Four images taken with the Cornell All-Sky Imager of the 777.4 nm emission. GPS tracks for satellite 11 have been superimposed on the images. The square on each track denotes the location of the satellite when the image was taken. The middle panel shows the S4 scintillation index recorded for satellite 11. The shaded times correspond to when the look direction to the satellite traversed through the depleted regions in the images. Note that no images were available before 2222 LT. The bottom panel shows the relative total electron content (TEC) as calculated by the NovAtel receiver. The data gaps correspond to times when the receiver loss lock on the L2 signal, rendering calculation of the TEC impossible.***

## IMPACT/APPLICATIONS

We have shown the need for testing data assimilation methods in ionospheric Space Weather research. Many parameters influence the system and researchers must be alert to the possibility that important factors may be overlooked. Reproducing a single parameter with good results may be incorrect if the wrong driver is adjusted.

We have also laid the groundwork for verifying the long-term potential of space-based imaging systems in the fields of ionospheric research and Space Weather.

## TRANSITIONS

One major transition was the improvement of one of the major data assimilation models being developed with Navy support and under a MURI Program. Because of this work the version AIM 1.06 was upgraded to AIM 1.07. Our continued work with ground and space-based systems has positively impacted plans by both NASA and DOD concerning the long-term worth of orbiting imagers.

## RELATED PROJECTS

None.

## REFERENCES

Kelley, M.C., J.J. Makela, B.M. Ledvina, and P.M. Kintner, Observations of equatorial spread-*F* from Haleakala, Hawaii, *Geophys. Res. Lett.*, *29*(20), 2003, doi:10.1029/ 2002GL015509, 2002.

Kelley, M.C., A. Sur, J.J. Makela, and M.N. Vlasov, Further studies of the Perkins stability during space weather month, *J. Atmos. Solar-Terr. Phys.*, in press, 2003.

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## PUBLICATIONS

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**HONORS/AWARDS/PRIZES**

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